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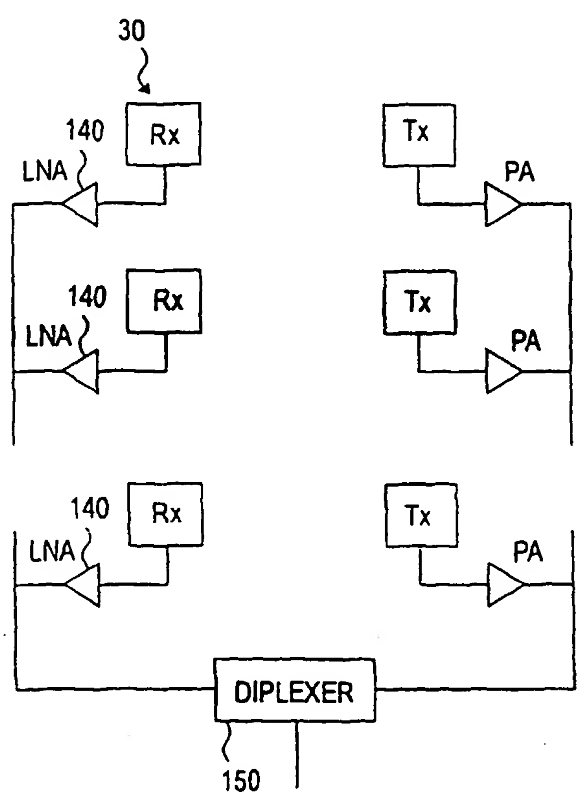
(54) Title: DISTRIBUTED ANTENNA SYSTEMS



(57) Abstract: A distributed antenna device includes a plurality of transmit antenna elements (12), a plurality of receive antenna elements (30) and a plurality of amplifiers (14, 140). One of the amplifiers (14) is a relatively low power, linear amplifier operatively coupled with each of the transmit antenna elements (12) and mounted closely adjacent to the associated transmit antenna element (12), such that no appreciable power loss occurs between the power amplifier (14) and the associated antenna element (12). At least one of the amplifiers (140) is a low noise amplifier and is built into the distributed antenna device for receiving and amplifying signals from at least one of the receive antenna device for receiving and amplifying signals from at least one of the receive antenna elements (30).

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DISTRIBUTED ANTENNA SYSTEMS

Field of the Invention

This invention is directed generally to active antennas and more particularly to an integrated active antenna for multi-carrier applications. This invention is also directed to novel antenna structures and systems including an antenna array for both transmit (Tx) and receive (Rx) operations.

Background of the Invention

In communications equipment such as cellular and Personal Communications Service (PCS), as well as multi-channel multi-point distribution systems (MMDS) and local multi-point distribution systems (LMDS), it has been conventional to receive and retransmit signals from users or subscribers utilizing antennas mounted at the tops of towers or other structures. Other communications systems such as wireless local loop (WLL), specialized mobile radio (SMR), and wireless local area network (WLAN), have signal transmission infrastructure for receiving and transmitting communications between system users or subscribers which may also utilize various forms of antennas and transceivers.

All of these communications systems require amplification of the signals being transmitted by the antennas. For this purpose, it has heretofore been the practice to use a conventional linear power amplifier system placed at the bottom of the tower or other structure, with relatively long coaxial cables connecting with antenna elements mounted on the tower. The power losses experienced in the cables may necessitate some increases in the power amplification which is typically provided at the ground level infrastructure or base station, thus further increasing the expense per unit or cost per watt.

Output power levels for infrastructure (base station) applications in many of the foregoing communications systems are typically in excess of ten watts, and often up to hundreds of watts, which results in a relatively high effective isotropic power requirement (EIRP). For example, for a typical base station with a twenty-watt power output (at ground level), the power delivered to the antenna, minus cable losses, is around ten watts. In this case, half of the power has been consumed in cable loss/heat. Such systems require complex linear amplifier components cascaded into high power circuits to achieve the required linearity at the higher

output power. Typically, for such high power systems or amplifiers, additional high power combiners must be used.

All of this additional circuitry to achieve linearity of the overall system, which is required for relatively high output systems, results in a relatively high cost per unit/watt.

The present invention proposes placing linear amplifiers in the tower close to the antenna(s) and also, distributing the power across multiple antenna (array) elements, to achieve a lower power level per antenna element and utilize power amplifier technology at a much lower cost level (per unit/per watt).

In accordance with one aspect of the invention, linear (multi-carrier) power amplifiers of relatively low power are utilized. In order to utilize such relatively low power amplifiers, the present invention proposes use of an antenna array in which one relatively low power linear amplifier is utilized in connection with each antenna element of the array to achieve the desired overall output power of the array.

Moreover, the invention proposes installing a linear power amplifier of this type at or near the feed point of each element of a multi-element antenna array. Thus, the output power of the antenna system as a whole may be multiplied by the number of elements utilized in the array while maintaining linearity.

Furthermore, the present invention does not require relatively expensive high power combiners, since the signals are combined in free space (at the far field) at the remote or terminal location via electromagnetic waves. Thus, the proposed system uses low power combining, avoiding otherwise conventional combining costs. Also, in tower applications, the system of the invention eliminates the power loss problems associated with the relatively long cable which conventionally connects the amplifiers in the base station equipment with the tower-mounted antenna equipment, i.e., by eliminating the usual concerns with power loss in the cable and contributing to a lesser power requirement at the antenna elements. Thus, by placing the amplifiers close to the antenna elements, amplification is accomplished after cable or other transmission line losses usually experienced in such systems. This may further decrease the need for low loss cables, thus further reducing overall system costs.

The use of multi-carrier linear power amplifiers at or near the feed point of each element in the multi-element antenna array improves transmit efficiency, receive sensitivity and reliability for multi-carrier communications systems.

In accordance with another aspect of the invention, a distributed antenna device comprises a plurality of transmit antenna elements, a plurality of receive antenna elements, and a plurality of power amplifiers, one of said power amplifiers being operatively coupled with each of said transmit antenna elements and mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element, at least one of said power amplifiers comprising a low noise amplifier and being built into said distributed antenna device for receiving and amplifying signals from at least one of said receive antenna elements, each said power amplifier comprising a relatively low power, relatively low cost per watt linear power amplifier chip.

<u>Brief Description of the Drawings</u>

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with a general description of the invention given above, and the detailed description of the embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a simplified schematic of an antenna array utilizing linear power amplifier modules in accordance with one form of the invention;

FIG. 2 is a schematic similar to FIG. 1 in showing an alternate embodiment;

FIG. 3 is a block diagram of an antenna assembly or system in accordance with one aspect of the invention;

FIG. 4 is a block diagram of a communications system base station utilizing a tower or other support structure, and employing an antenna system in accordance with one aspect of the invention;

FIG. 5 is a block diagram of a communications system base station employing the antenna system in accordance with another aspect of the invention;

FIG. 6 is a block diagram of a communications system base station employing the antenna system in accordance with yet another aspect of the invention;

FIG. 7 and 8 are block diagrams of two types of communications system base stations utilizing the antenna system in accordance with still yet another aspect of the invention;

FIG. 8A is a simplified schematic of one form of linear amplifier, which may be used in connection with the invention;

FIG. 9 is a block diagram of a transmit/receive antenna system in accordance with one form of the invention.

FIG. 10 is a block diagram of a transmit/receive antenna system in accordance with another form of the invention;

FIG. 11 is a block diagram of a transmit/receive antenna system including a center strip in accordance with another form of the invention;

FIG. 12 is a block diagram of an antenna system employing transmit and receive elements in a linear array in accordance with another aspect of the invention;

FIG. 13 is a block diagram of an antenna system employing antenna array elements in a layered configuration with microstrip feedlines for respective transmit and receive functions oriented in orthogonal directions to each other;

FIG. 14 is a partial sectional view through a multi-layered antenna element which may be used in the arrangement of FIG. 13;

FIGS. 15 and 16 show various configurations of directing input and output RF from a transmit/receive antenna such as the antenna of FIGS. 13 and 14;

FIGS. 17 and 18 are block diagrams showing two embodiments of a transmit/receive active antenna system with respective alternative arrangements of diplexers and power amplifiers;

FIG. 19 is an exploded view of an embodiment of an active antenna system;

FIG. 20 is an assembled view of an embodiment of FIG. 19;

FIG. 21 is an exploded view, similar to FIG. 19, showing another embodiment of an active antenna system; and

FIG. 22 is an assembled view of the embodiment of FIG. 21.

Detailed Description of the Preferred Embodiment

Referring now to the drawings, and initially to FIGS. 1 and 2, there are shown two examples of a multiple antenna element antenna array 10, 10a in accordance with the invention. The antenna array 10, 10a of FIGS. 1 and 2 differ in the configuration of the feed structure utilized, FIG. 1 illustrating a parallel corporate feed structure and FIG. 2 illustrating a series corporate feed structure. In other respects, the two antenna arrays 10, 10a are substantially identical. Each of the arrays 10, 10a includes a plurality of antenna elements 12, which may comprise monopole, dipole or microstrip/patch antenna elements. Other types of antenna elements may be utilized to form the arrays 10, 10a without departing from the invention.

In accordance with one aspect of the invention, a multi-carrier, linear amplifier 14 is operatively coupled to the feed of each antenna element 12 and is mounted in close proximity to the associated antenna element 12. In one embodiment, the amplifiers 14 are mounted sufficiently close to each antenna element so that no appreciable losses will occur between the amplifier output and the input of the antenna element, as might be the case if the amplifiers were coupled to the antenna elements by a length of cable or the like. For example, the power amplifiers 14 may be located at or near the feed point of each antenna element.

In an alternative embodiment, the power amplifiers 14 may comprise relatively low power, linear integrated circuit chip components, such as monolithic microwave integrated circuit (MMIC) chips. These chips may comprise chips made by the gallium arsenide (GaAs) heterojunction transistor manufacturing process. However, silicon process manufacturing or CMOS process manufacturing might also be utilized to form these chips.

Some examples of MMIC power amplifier chips are as follows:

1. RF Microdevices PCS linear power amplifier RF 2125P, RF 2125, RF 2126 or RF 2146, RF Micro Devices, Inc., 7625 Thorndike Road, Greensboro, NC 27409, or 7341-D W. Friendly Ave., Greensboro, NC 27410;

2. Pacific Monolithics PM 2112 single supply RF IC power amplifier, Pacific Monolithics, Inc., 1308 Moffett Park Drive, Synnyvale, CA;

3. Siemens CGY191, CGY180 or CGY181, GaAs MMIC dual mode power amplifier, Siemens AG, 1301 Avenue of the Americas, New York, NY;

4. Stanford Microdevices SMM-208, SMM-210 or SXT-124, Stanford Microdevices, 522 Almanor Avenue, Sunnyvale, CA;

5. Motorola MRFIC1817 or MRFIC1818, Motorola Inc., 505 Barton Springs Road, Austin, TX;

6. Hewlett Packard HPMX-3003, Hewlett Packard Inc., 933 East Campbell Road, Richardson, TX;

7. Anadigics AWT1922, Anadigics, 35 Technology Drive, Warren, NJ 07059;

8. SEI Ltd. P0501913H, 1, Taya-cho, Sakae-ku, Yokohama, Japan; and

9. Celeritek CFK2062-P3, CCS1930 or CFK2162-P3, Celeritek, 3236 Scott Blvd., Santa Clara, CA 95054.

In the antenna arrays of FIGS. 1 and 2, array phasing may be adjusted by varying the line length in the corporate feed or by electronic circuitry within the power amplifiers 14. The array amplitude coefficient adjustment may be accomplished through the use of attenuators before or within the power amplifiers 14, as shown in FIG. 3.

Referring now to FIG. 3, an antenna system in accordance with the invention and utilizing an antenna array of the type shown in either FIG. 1 or FIG. 2 is designated generally by the reference numeral 20. The antenna system 20 includes a plurality of antenna elements 12 and associated multi-carrier linear power amplifiers 14 as described above in connection with FIGS. 1 and 2. Also operatively coupled in series circuit with the power amplifiers 14 are suitable attenuator circuits 22. The attenuator circuits 22 may be interposed either before or within the power amplifier 14; however, FIG. 3 illustrates them at the input to each power amplifier 14. A power splitter and phasing network 24 feeds all of the power amplifiers 14 and their associated series connected attenuator circuits 22. An RF input 26 feeds into this power splitter and phasing network 24.

Referring to FIG. 4, an antenna system installation utilizing the antenna system 20 of FIG. 3 is designated generally by the reference numeral 40. FIG. 4 illustrates a base

station or infrastructure configuration for a communications system such as a cellular system, a personal communications system PCS or a multi-channel multipoint distribution system (MMDS). The antenna structure or assembly 20 of FIG. 3 is mounted at the top of a tower or other support structure 42. A DC bias tee 44 separates signals received via a coaxial cable 46 into DC power and RF components, and conversely receives incoming RF signals from the antenna system 20 and delivers the same to the coaxial line or cable 46 which couples the tower-mounted components to ground based components. The ground-based components may include a DC power supply 48 and an RF input/output 50 from a transmitter/receiver (not shown), which may be located at a remote equipment location, and hence is not shown in FIG. 4. A similar DC bias 52 receives the DC supply and RF input and couples them to the coaxial line 46, and conversely delivers signals from the antenna structure 20 to the RF input/output 50.

FIG. 5 illustrates a communications system base station employing the antenna structure or system 20 as described above. In similar fashion to the installation of FIG. 4, the installation of FIG. 5 mounts the antenna system 20 atop a tower/support structure 42. Also, a coaxial cable 46, for example, an RF coaxial cable for carrying RF transmissions, runs between the top of the tower/support structure and ground based equipment. The ground based equipment may include an RF transceiver 60 which has an RF input from a transmitter. Another similar RF transceiver 62 is located at the top of the tower and exchanges RF signals with an antenna structure or system 20. A power supply such as a DC supply 48 is also provided for the antenna system 20, and is located at the top of the tower 42 in the embodiment shown in FIG. 5.

Alternatively, the two transceivers 60, 62 may be RF-to-fiber optic transceivers (as shown for example, in FIG. 8), and the cable 46 may be a fiber optic or "optical fiber" cable, e.g., as shown in FIG. 8.

FIG. 6 illustrates a communications system base station which also mounts an antenna structure or system 20 of the type described above at the top of a tower/support structure 42. In similar fashion to the installation of FIG. 5, an RF transceiver and power supply such as a DC supply 48 are also located at the top of the tower/support and are operatively coupled with the antenna system 20. A second or remote RF transceiver 60 may be located

adjacent the base of the tower or otherwise within a range of a wireless link which links the transceivers 60 and 62, by use of respective transceiver antenna elements 64 and 66 as illustrated in FIG. 6.

FIGS. 7 and 8 illustrate examples of use of the antenna structure or system 20 of the invention in connection with communications system base stations, such as in-building communication applications by way of example. In FIG. 7, respective DC bias tees 70 and 72 are linked by an RF coaxial cable 74. The DC bias tee 70 is located adjacent the antenna system 20 and has respective RF and DC lines operatively coupled therewith. The second DC bias tee 72 is coupled to an RF input/output from a transmitter/receiver and to a suitable DC supply 48. The DC bias tees and DC supply operate in conjunction with the antenna system 20 and a remote transmitter/receiver (not shown) in much the same fashion as described hereinabove with reference to the system of FIG. 4.

In FIG. 8, the antenna system 20 receives an RF line from a fiber-RF transceiver 80, which is coupled through an optical fiber cable 82 to a second RF-fiber transceiver 84 which may be located remotely from the antenna and first transceiver 80. A DC supply or other power supply for the antenna may be located either remotely, as illustrated in FIG. 8 or adjacent the antenna system 20, if desired. The DC supply 48 is provided with a separate line operatively coupled to the antenna system 20, in much the same fashion as illustrated, for example, in the installation of FIG. 6.

FIG. 8A shows an example of a linear (multi-carrier) amplifier, which may be used as the amplifier 14. The amplifier in FIG. 8A is a feed forward design; however, other forms of linear (multi-carrier) amplifiers may be used without departing from the invention.

In one embodiment of the present invention, each of the amplifiers 14 has an input 86 operatively coupled to an RF transmitter/receiver (not shown) and an output 88 operatively coupled to the feed of each antenna element 12. The multi-carrier linear power amplifier 14 is designed to reduce or eliminate the distortion created by amplification of the feed signal in the feed forward amplifier 14.

To this end, the amplifier 14 has a power splitter 90 that directs the feed signal transmitted by the RF transmitter/receiver (not shown) to a main amplifier 92 and to an input 94

of a carrier cancellation node 96 through a delay 98. The main amplifier 92 receives the feed signal at an input 100 and generates a signal at its output 102 that comprises the feed signal amplified by a predetermined gain and distortion caused by amplification of the feed signal. The output signal generated by the main amplifier 92 is applied to a coupler 104 that directs the output signal of the main amplifier 92 to an attenuator 106 and to an input 108 of a distortion cancellation node 110 through a delay 112.

The attenuator 106 attenuates the output signal generated by the main amplifier 92 and applies the attenuated signal to a second input 114 of the carrier cancellation node 96. The carrier cancellation node 96 utilizes the signals received at inputs 94 and 114 to remove the carrier signal from the attenuated signal applied by the attenuator 106 and generate a distortion signal at its output 116 that is applied to input 118 of an error amplifier 120.

The error amplifier 120 amplifies the distortion signal generated by the carrier cancellation node 96 and applies the amplified distortion signal to a second input 122 of the distortion cancellation node 110. The distortion cancellation node 110 utilizes the signals received at inputs 108 and 122 to remove the distortion in the amplified feed signal applied by the main amplifier 92 and generate an essentially distortion-free amplified feed signal at its output 88 that is applied to the feed of an antenna element 12.

Referring now to FIGS. 9-16, the various embodiments of the invention shown have a number of characteristics, three of which are summarized below:

1) Use of two different patch elements; one transmit, and one receive. This results in substantial RF signal isolation (over 20 dB isolation, at PCS frequencies, by simply separating the patches horizontally by 4 inches) without requiring the use of a frequency diplexer at each antenna element (patch). This technique can be used on virtually any type of antenna element (dipole, monopole, microstrip/patch, etc.).

In some embodiments of a distributed antenna system, we use a collection of elements (M vertical Tx elements 12, and M vertical Rx elements 30), as shown in FIGS. 9, 10 and 11. FIGS. 9 and 10 show the elements in a series corporate feed structure, for both the Tx and Rx. Note that they can also be in a parallel corporate feed structure (not shown); or the Tx

in a parallel corporate feed structure, and receive elements in a series feed structure (or vice versa).

2) Use of a "built-in" Low Noise Amplifier (LNA) circuit or device; that is, built directly into the antenna, for the receive (Rx) side. FIG. 9 shows the LNA 140 after the antenna elements 30 are summed via the series (or parallel) corporate feed structure. FIG. 10 shows the LNA devices 140 (discrete devices) at the output of each Rx element (patch), before being RF summed.

The LNA device 140 at the Rx antenna reduces the overall noise figure (NF), and increases the sensitivity of the system, to the signal emitted by the remote radio. This, therefore, helps to increase the range of the receive link (uplink).

The similar use of power amplifier devices 14 (chips) at the transmit (Tx) elements has been discussed above.

3) Use of a low power frequency diplexer 150 (shown in FIGS. 9 and 10). In conventional tower top systems (such as "Cell Boosters"), since the power delivered to the antenna (at the input) is high power RF, a high power frequency diplexer must be used (within the Cell Booster, at the tower top). In our system, since the RF power delivered to the (Tx) antenna is low (typically less than 100 milliwatts), a low power diplexer 150 can be used.

Additionally, in conventional system, the diplexer isolation is typically required to be well over 60 dB, often up to 80 or 90 dB isolation between the uplink and downlink signals.

Since the power output from our system, at each patch, is low power (less than 1-2 Watts typical), and since we have already achieved (spatial) isolation via separating the patches, the isolation requirements of our diplexer is much less.

In each of the embodiments illustrated herein, a final transmit rejection filter (not shown) would be used in the receive path. This filter might be built into the or each LNA if desired; or might be coupled in circuit ahead of the or each LNA.

Referring now to FIG. 11, this embodiment uses two separate antenna elements (arrays), one for transmit 12, and one for receive 30, e.g., a plurality of transmit (array) elements 12, and a plurality of receive (array) elements 30. The elements can be dipoles, monopoles, microstrip (patch) elements, or any other radiating antenna element. The transmit element

(array) will use a separate corporate feed (not shown) from the receive element array. Each array (transmit 12 and receive 30) is shown in a separate vertical column; to shape narrow elevation beams. This can also be done in the same manner for two horizontal rows of arrays (not shown); shaping narrow azimuth beams.

Separation (spatial) of the elements in this fashion increases the isolation between the transmit and receive antenna bands. This acts similarly to the use of a frequency diplexer coupled to a single transmit/receive element. Separation by over half a wavelength typically assures isolation greater than 10dB.

The backplane/reflector 155 can be a flat ground plane, a piecewise or segmented linear folded ground plane, or a curved reflector panel (for dipoles). In either case, one or more conductive strips 160 (parasitic) such as a piece of metal can be placed on the backplane to assure that the transmit and receive element radiation patterns are symmetrical with each other, in the azimuth plane; or in the plane orthogonal to the arrays. FIG. 11 illustrates an embodiment where a single center strip 160 is used for this purpose and is described below. However, multiple strips could also be utilized, for example over more strips to either side of the respective Tx and Rx antenna element(s). This can also be done for antenna elements (Tx, Rx) oriented in a horizontal array (not shown); i.e., assuring symmetry in the elevation plane. For antenna elements (Tx, Rx) which are non-centered on the ground plane 155, as shown in FIG. 11, the resulting radiation patterns are typically non-symmetric; that is, the beams tend to skew away from the azimuth center point. The center strip 160 (metal) "pulls" the radiation pattern beam, for each array, back towards the center. This strip 160 can be a solid metal (aluminum, copper, . . .) bar; in the case of dipole antenna elements, or a simple copper strip in the case of microstrip/patch antenna elements. In either case, the center strip 160 can be connected to ground or floating; i.e. not connected to ground. Additionally, the center strip 160 (or bar) further increases the isolation between the transmit and receive antenna arrays/elements.

The respective Tx and Rx antenna elements can be orthogonally polarized relative to each other to achieve even further isolation. This can be done by having the receive elements 30 in a horizontal polarization, and the transmit elements 12 in a vertical polarization, or vice-

versa. Similarly, this can be accomplished by operating the receive elements 30 in slat-45 degree (right) polarization, and the transmit elements 12 in slant-45 degree (left) polarization, or vice versa.

Vertical separation of the elements 12 in the transmit array is chosen to achieve the desired beam pattern, and in consideration of the amount of mutual coupling that can be tolerated between the elements 12 (in the transmit array). The receive elements 30 are vertically spaced by similar considerations. The receive elements 30 can be vertically spaced differently from the transmit elements 12; however, the corporate feed(s) must be compensated to assure a similar receive beam pattern to the transmit beam pattern, across the desired frequency band(s). The phasing of the receive corporate feed usually will be slightly compensated to assure a similar pattern to the transmit array.

Most existing Cellular/PCS antennas use the same antenna element or array for both transmit and receive. The typical arrangement has a RF cable going to the antenna, which uses a parallel corporate feed structure; thus all the feed paths, and the elements, handle both the transmit and receive signals. Thus, for these types of systems, there isn't a need to separate the elements into separate transmit and receive functionalities. The characteristics of this approach are:

a) A single (1) antenna element (or array) used; for both Tx and Rx operation.

b) No constriction or restriction on geometrical configuration.

c) One (1) single corporate feed structure, for both Tx and Rx operation.

d) Element is polarized in the same plane for both Tx and Rx.

For (c) and (d), there are some cases (i.e. dual polarized antennas) that use cross-polarized antennas (literally two antenna structures, or sub-elements, within the same element), with the Tx functionality with its own sub-element and corporate feed structure, and the Rx functionality with its own sub-element and separate corporate feed structure.

In FIG. 11, we split up the transmit and receive functionalities into separate transmit and receive antenna elements, so as to allow separation of the distinct bands (transmit and receive). This provides added isolation between the bands, which in the case of the receive

path, helps to attenuate (reduce the power level of the signals in the transmit band), prior to amplification. Similarly, for the transmit paths, we only (power) amplify the transmit signals using the active components (power amplifiers) prior to feeding the amplified signal to the transmit antenna elements.

As mentioned above, the center strip aids in correcting the beams from steering outwards. In a single column array, where the same elements are used for transmit and receive, the array would likely be placed in the center of the antenna (ground plane) (see e.g., FIG. 12, described below). Thus, the azimuth beam would be centered (symmetric) orthogonal to the ground plane. However, by using adjacent vertical arrays (one for Tx and one for Rx), the beams become asymmetric and steer outwards by a few degrees. Placement of a parasitic center strip between the two arrays "pulls" each beam back towards the center. Of course, this can be modeled to determine the correct strip width and placement(s) and locations of the vertical arrays, to accurately center each beam.

The characteristics of this approach are:

a) Two (2) different antenna elements (or arrays) used; one for Tx and one for Rx.

b) Geometrical configuration is spaced apart, adjacent placement of Tx and Rx elements (as shown in FIG. 11).

c) Two (2) separate corporate feed structures used, one for Tx and one for Rx.

d) Each element can be polarized in the same plane, or an arrangement can be constructed where the Tx element(s) are in a given polarization, and the Rx elements are all in an orthogonal polarization.

The embodiment of FIG. 12 uses two separate antenna elements, one for transmit 12, and one for receive 30, or a plurality of transmit (array elements, and a plurality of receive (array) elements. The elements can be dipoles, monopoles, microstrip (patch) elements, or any other radiating antenna element. The transmit element array will use a separate corporate feed from the receive element array. However, all elements are in a single vertical column; for beam shaping in the elevation plane. This arrangement can also be used in a single horizontal

row (not shown), for beam shaping in the azimuth array. This method assures highly symmetric (centered) beams, in the azimuth plane, for a column (of elements); and in the elevation plane, for a row (of elements).

The individual Tx and Rx antenna elements in FIG. 12, can be orthogonally polarized to each other to achieve even further isolation. This can be done by having the receive patches 30 (or elements, in the receive array) in the horizontal polarization, and the transmit patches 12 (or elements) in the vertical polarization, or vice-versa. Similarly, this can be accomplished by operating the receive elements in slant-45 degree (right) polarization, and the transmit elements in slant-45 degree (left) polarization, or vice-versa.

This technique allows placing the all elements down a single center line. This results in symmetric (centered) azimuth beams, and reduces the required width of the antenna. However, it also increases the mutual coupling between antenna elements, since they should be packed close together, so as to not create ambiguous elevation lobes.

The characteristics of this approach are:

a) Two (2) different antenna elements (or arrays) used; one for Tx and one for Rx.

b) Geometrical configuration is adjacent, collinear placement.

c) Two (2) separate corporate feed structures used, one for Tx and one for Rx.

d) Each element is polarized in the same plane, or the Tx element(s) are all in a given polarization, and the Rx elements are all in an orthogonal polarization.

The embodiment of FIG. 13 uses a single antenna element (or array), for both the transmit and receive functions. In this case, a patch (microstrip) antenna element is used. The patch element 170 is created via the use of a multi-element (4-layer) printed circuit board, with dielectric layers 183, 185, 187 (see FIG. 14). The antennas can be fed with either a coaxial probe (not shown), or aperture coupled probes or microstriplines 180, 182. For the receive function, the feed microstripline 182 is oriented orthogonal to the feed stripline (probe) 180 for the transmit function.

The elements can be cascaded, in an array, as shown in FIG. 13, for beam shaping purposes. The RF input 190 is directed towards the radiation elements via a separate corporate feed from the RF output 192 (on the receive corporate feed), ending at point "A." Note that either or both corporate feeds 180, 182 can be parallel or series corporate feed structures.

The diagram of FIG. 13 shows that the receive path RF is summed in a series corporate feed, ending at point "A" (192) preceded by a low noise amplifier (LNA). However, low noise amplifiers, (LNAs), can be used directly at the output of each of the receive feeds (not shown in FIG. 13), prior to summing, similar to the showing in FIG. 9, as discussed above.

The transmit and receive RF isolation is achieved via orthogonal polarization taps from the same antenna (patch) element, as shown and described above with reference to FIGS. 13 and 14. FIG. 14 indicates, in cross-section, the general layered configuration of each element 170 of FIG. 13. The respective feeds 180, 182 are separated by a dielectric layer 183. Another dielectric layer 185 separates the feed 182 from a ground plane 186, while yet a further dielectric layer separates the ground plane 186 from a radiating element or "patch" 188.

This concept uses the same antenna physical location for both functionalities (Tx and Rx). A single patch element (or cross polarized dipole) can be used as the antenna element, with two distinct feeds (one for Tx, and the other for Rx at orthogonal polarization). The two antenna elements (Tx and Rx) are orthogonally polarized, since they occupy the same physical space.

The characteristics of this approach are:

a) One (1) single antenna element (or array), used for both Tx and Rx.

b) No construct on geometrical configuration.

c) Two (2) separate corporate feed structures used, one for Tx and one for Rx.

d) Each element contains two (2) sub-elements, cross polarized (orthogonal) to one another.

The embodiments of FIGS. 15-16 show two (2) ways to direct the input and output RF from the Tx/Rx active antenna, to the base station.

FIG. 15 shows the output RF energy, at point 192 (of FIG. 13), and the input RF energy, going to point 190 (of FIG. 13), as two distinctly different cables 194, 196. These cables can be coaxial cables, or fiber optic cables (with RF/analog to fiber converters, at points "A" and "B"). This arrangement does not require a frequency diplexer at the antenna (tower top) system. Additionally, it does not require a frequency diplexer (used to separate the transmit band and receive band RF energies) at the base station.

FIG. 16 shows the case where the output RF energy (from the receive array) and the input RF energy (going to the transmit array), are diplexed together (via a frequency diplexer 400), within the antenna system so that a single cable 198 runs down the tower (not shown) to the base station 404. Thus, the output/input to the base station 404 is via a single coaxial cable (or fiber optic cable, with RF/analog to fiber optic converter). This system requires another frequency diplexer 402 at the base station 404.

FIGS. 17 and 18 show another arrangement which may be used as a transmit/receive active antenna system. The array comprises a plurality of antenna elements 410 (dipoles, monopoles, microstrip patches, . . .) with a frequency diplexer 412 attached directly to the antenna element feed of each element.

In FIG. 17, the RF input energy (transmit mode) is split and directed to each element, via a series corporate feed structure 415 (this can be microstrip, stripline, or coaxial cable), but can also be a parallel corporate feed structure (not shown). Prior to each diplexer 412, is a power amplifier (PA) chip or module 414. The RF output (receive mode) is summed in a separate corporate feed structure 416, which is amplified by a single LNA 420, prior to point "A," the RF output 422.

In FIG. 18, there is an LNA 420 at the output of each diplexer 412, for each antenna (array) element 410. Each of these are then summed in the corporate feed 425 (series or parallel), and directed to point "A," the RF output 422.

The arrangements of FIGS. 17 and 18 can employ either of the two connections (described in FIGS. 15 and 16), for connection to the base station 404 (transceiver equipment).

In FIGS. 19-22, like reference numerals are utilized to designate like elements and components to those shown, for example, in the previous figures.

In FIGS. 19 and 20, a housing including a radome cover 200 and a radome back 210 enclose an active antenna structure including patches 188 which are mounted on a dielectric board 187 and may have a number of drain lines 202, formed on the dielectric board for lightning or other electrostatic discharge (ESD) protection. These drain lines 202 are coupled to a source of ground potential such as a ground plane. The embodiment of FIGS. 19 and 20 also includes a ground plane 186 as described above with reference to FIGS. 13 and 14. In FIG. 19, the ground plane is a dielectric sheet with metallization on the side facing the dielectric sheet 187. The opposite side of ground plane 186 has an etched feed pattern forming a feed network for the patches 188. Through apertures 204 are provided for coupling the feed network to the patches 188. This back surface of sheet 186 may also carry some of the electronic components, as shown in FIGS. 16-18.

The radome back or housing 210 also mounts a PC board 215 which may contain electronic components, such as one or more amplifiers 414, 420 and diplexers 400, 402 and/or 412, as shown for example in FIGS. 16-18. Additional end covers 212, 214 for the housing comprising the radome cover and back 200, 210 are also illustrated in FIGS. 19 and 20. It will be seen that two columns of patch antenna elements 188 are illustrated in FIG. 19, whereby one of these columns may act as transmit antenna elements and the other as receive antenna elements, if desired.

In the embodiment of FIGS. 21 and 22, a similar dielectric layer 187 mounts a plurality of patch elements 188 (in a single column) which are provided with drain lines 202, for example, printed on the dielectric surface 187 for electro static discharge protection. These drain lines 202, as described above, with reference to FIG. 19, are coupled to a suitable ground potential. The ground plane 186 is constructed similarly to that described above with reference to FIG. 19. An electronics PC board is indicated by reference numeral 315. Similar to the embodiment of FIGS. 14 and 15, a radome cover 300 and radome back 310 are provided, as well as respective end covers 312, 314.

What has been shown and described herein is a novel antenna array employing power amplifier chips or modules at or near the feed of individual array antenna elements, and novel installations utilizing such an antenna system.

While particular embodiments and applications of the present invention have been illustrated and described, it is to be understood that the invention is not limited to the precise construction and compositions disclosed herein and that various modifications, changes, and variations may be apparent from the foregoing descriptions, and are to be understood as forming a part of the invention insofar as they fall within the spirit and scope of the invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A distributed antenna array comprising:

a plurality of antenna elements, and

a plurality of power amplifiers, each power amplifier being operatively coupled with one of said antenna and mounted closely adjacent to the associated antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element;

each said power amplifier comprising a relatively low power, linear power amplifier.

2. The antenna array of claim 1 wherein each antenna element is a dipole.

3. The antenna array of claim 1 wherein each element is a monopole.

4. The antenna element of claim 1 wherein each antenna element is a microstrip/patch antenna element.

5. The antenna array of claim 1 and further including an attenuator circuit operatively coupled in series with each linear power amplifier for adjusting array amplitude coefficients.

6. The antenna array of claim 1 and further including a power splitter and phasing network operatively coupled with all of said linear power amplifiers.

7. The antenna array of claim 5 and further including a power splitter and phasing network operatively coupled with all said linear power amplifiers.

8. The antenna array of claim 1 wherein said antenna elements and said linear power amplifiers are coupled to a parallel feed structure.

9. The antenna array of claim 1 wherein said antenna elements and said linear power amplifiers are coupled to a series feed structure.

10. The antenna array of claim 1 wherein said antenna elements and said linear power amplifiers are coupled to a feed structure.

11. The antenna array of claim 10 wherein line length in the feed structure is selected to obtain a desired array phasing.

12. An antenna system installation comprising a tower/support structure, and an antenna structure mounted at the top of said tower/support structure, said antenna structure comprising:

a plurality of antenna elements; and

a plurality of power amplifiers, each power amplifier being operatively coupled with one of said antenna elements and mounted closely adjacent to the associated antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element;

each said power amplifier comprising a relatively low power, linear power amplifier.

13. The installation of claim 12 and further including a DC bias tee mounted on said tower/support structure and operatively coupled with said antenna structure.

14. The installation of claim 13 and further including a coaxial line operatively coupled with said DC bias tee and running to a ground-based second DC bias tee adjacent a base portion of said tower/support structure, said second DC bias tee being operatively coupled to a DC supply and an RF input/output from a transmitter/receiver.

15. The installation of claim 12 and further including a first RF transceiver and a power supply mounted at the top of said tower/support structure and operatively coupled with said antenna structure.

16. The installation of claim 15 and further including a second RF transceiver structure mounted adjacent a base portion of said tower/support structure and coupled with said first RF transceiver by a coaxial cable.

17. The installation of claim 15 and further including a second RF transceiver and a wireless link for carrying communications between said the first RF transceiver and said second RF transceiver.

18. An in-building antenna system installation comprising an antenna structure including:

a plurality of antenna elements, and

a plurality of power amplifiers, each power amplifier being operatively coupled with one said antenna elements and mounted closely adjacent to the associated antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element;

each said power amplifier comprising a relatively low power linear power amplifier.

19. The installation of claim 20 and further including:

a DC bias tee mounted operatively coupled with said antenna structure; a coaxial line operatively coupled with said DC bias tee and running to a second DC bias tee, said second DC bias tee being operatively coupled to a DC supply and an RF input/output from a transmitter/receiver.

20. The in-building antenna system installation of claim 18 and further including:

a fiber-RF transceiver operatively coupled with said antenna structure;

a second fiber-RF transceiver, and a fiber-optic coupling the two fiber-RF transceivers.

21. The installation of claim 19 and further including a power supply coupled to said antenna structure.

22. A distributed antenna device comprising:

a plurality of transmit antenna elements;

a plurality of receive antenna elements; and

a plurality of power amplifiers, a power amplifier being operatively coupled with each of said transmit antenna elements and mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element; and

at least one low noise amplifier for receiving and amplifying signals from at least one of said receive antenna elements;

each said power amplifier comprising a relatively low power, relatively low cost per watt linear power amplifier; and

said device being configured such that said transmit antenna elements and said power amplifiers coupled thereto, and said receive antenna elements and said at least one low noise amplifier coupled thereto are continuously active and capable of simultaneous respective transmit and receive operations;

wherein said transmit antenna elements are spaced apart to achieve a given beam pattern and no more than a given amount of mutual coupling, and wherein said receive antenna elements are spaced apart to achieve a given beam pattern and no more than a given amount of mutual coupling.

23. The antenna device of claim 22 wherein each said power amplifier chip has an output not greater than about one watt.

24. The antenna device of claim 22 and further including a plurality of low noise amplifiers, each operatively coupled with one of said receive antenna elements.

25. The antenna device of claim 22 wherein each antenna element is a dipole.

26. The antenna device of claim 22 wherein each antenna element is a monopole.

27. The antenna device of claim 22 wherein each antenna element is a microstrip/patch antenna element.

28. The antenna device of claim 22 wherein a single low noise amplifier is operatively coupled to a summed output of all of said receive elements.

29. The antenna device of claim 22 and further including a low power frequency diplexer operatively coupled with all of said power amplifiers for coupling a single RF cable to all of said transmit and receive antenna elements.

30. The antenna device of claim 22 wherein said receive antenna elements are in a first linear array and said transmit antenna elements are in a second linear array spaced apart from and parallel to said first linear array.

31. A distributed antenna device comprising:

a plurality of transmit antenna elements;

a plurality of receive antenna elements; and

a plurality of power amplifiers, a power amplifier being operatively coupled with each of said transmit antenna elements and mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element; and

at least one low noise amplifier for receiving and amplifying signals from at least one of said receive antenna elements;

each said power amplifier comprising a relatively low power, relatively low cost per watt linear power amplifier; and

said device being configured such that said transmit antenna elements and said power amplifiers coupled thereto, and said receive antenna elements and said at least one low noise amplifier coupled thereto are continuously active and capable of simultaneous respective transmit and receive operations;

wherein said receive antenna elements are in a first linear array and said transmit antenna elements are in a second linear array spaced apart from and parallel to said first linear array; and

further including an electrically conductive center strip element positioned between the first and second linear arrays.

32. The antenna device of claim 31 wherein said receive antenna elements are coupled to one of a series and a parallel corporate feed structure.

33. The antenna device of claim 32 wherein said transmit antenna elements are coupled to one of a series and a parallel corporate feed structure.

34. The antenna device of claim 31 wherein a single transmit RF cable is coupled to all of said power amplifiers to carry signals to be transmitted to said antenna device and a single receive RF cable is coupled to said at least one low noise amplifier to carry received signals away from said antenna device.

35. The antenna device of claim 31 wherein said receive antenna elements, said transmit antenna elements, and said center strip element are all mounted to a common backplane.

36. The antenna device of claim 35 wherein all of said power amplifiers are also mounted to said backplane.

37. A distributed antenna device comprising:

a plurality of transmit antenna elements;

a plurality of receive antenna elements; and

a plurality of power amplifiers, a power amplifier being operatively coupled with each of said transmit antenna elements and mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element; and

at least one low noise amplifier for receiving and amplifying signals from at least one of said receive antenna elements;

each said power amplifier comprising a relatively low power, relatively low cost per watt linear power amplifier; and

said device being configured such that said transmit antenna elements and said power amplifiers coupled thereto, and said receive antenna elements and said at least one low noise amplifier coupled thereto are continuously active and capable of simultaneous respective transmit and receive operations;

wherein said transmit antenna elements and said receive antenna elements are arranged in a single array in alternating order.

38. A distributed antenna device comprising:

a plurality of transmit antenna elements;

a plurality of receive antenna elements; and

a plurality of power amplifiers, a power amplifier being operatively coupled with each of said transmit antenna elements and mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element; and

at least one low noise amplifier for receiving and amplifying signals from at least one of said receive antenna elements;

each said power amplifier comprising a relatively low power, relatively low cost per watt linear power amplifier; and

said device being configured such that said transmit antenna elements and said power amplifiers coupled thereto, and said receive antenna elements and said at least one low noise amplifier coupled thereto are continuously active and capable of simultaneous respective transmit and receive operations;

wherein said transmit antenna elements and said receive antenna elements comprise separate arrays of antenna elements and wherein said transmit antenna elements are polarized in one polarization and the receive antenna elements are polarized orthogonally to the polarization of said transmit antenna elements.

39. The antenna device of claim 38 and further including a transmit corporate feed structure operatively coupled with said transmit antenna elements and a receive corporate feed structure operatively coupled with said receive antenna elements, and wherein one or both of said corporate feed structures are adjusted to cause the transmit beam pattern and receive beam pattern to be substantially similar.

40. The distributed antenna device of claim 38 wherein said transmit antenna elements are polarized in one polarization and the receive antenna elements are polarized orthogonally to the polarization of said transmit antenna elements.

41. The antenna device of claim 38 wherein said transmit antenna elements are coupled to a one of a series and a parallel corporate feed structure and said receive antenna elements are coupled to a one of a series and a parallel corporate feed structures.

42. A distributed antenna device comprising:

a plurality of transmit antenna elements;

a plurality of receive antenna elements; and

a plurality of power amplifiers, a power amplifier being operatively coupled with each of said transmit antenna elements and mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element; and

at least one low noise amplifier for receiving and amplifying signals from at least one of said receive antenna elements;

each said power amplifier comprising a relatively low power, relatively low cost per watt linear power amplifier; and

said device being configured such that said transmit antenna elements and said power amplifiers coupled thereto, and said receive antenna elements and said at least one low noise amplifier coupled thereto are continuously active and capable of simultaneous respective transmit and receive operations;

wherein a single array of patch antenna elements functions as both said transmit antenna elements and said receive antenna elements, and further including a transmit feed stripline and a receive feed stripline coupled to each of said patch antenna elements, said transmit feed stripline and said receive feed stripline being oriented orthogonally to each other at least in a region where they are coupled with each said patch element.

43. A method of operating a distributed antenna comprising:

arranging a plurality of transmit antenna elements in an array;

arranging a plurality of receive antenna elements in an array;

coupling a power amplifier with each of said transmit antenna elements mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element;

providing at least one low noise amplifier built into said distributed antenna for receiving and amplifying signals from at least one of said receive antenna elements;

simultaneously transmitting from said transmit antenna elements and receiving from said receive antenna elements; and

spacing said transmit antenna elements apart to achieve a given beam pattern and no more than a given amount of mutual coupling, and spacing said receive antenna elements apart to achieve a given beam pattern and no more than a given amount of mutual coupling.

44. A method of operating a distributed antenna comprising:

arranging a plurality of transmit antenna elements in an array;

arranging a plurality of receive antenna elements in an array;

coupling a power amplifier with each of said transmit antenna elements mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element;

providing at least one low noise amplifier built into said distributed antenna for receiving and amplifying signals from at least one of said receive antenna elements;

simultaneously transmitting from said transmit antenna elements and receiving from said receive antenna elements;

arranging said receive antenna elements in a first linear array and arranging said transmit antenna elements in a second linear array spaced apart from and parallel to said first linear array; and

positioning an electrically conductive center strip element between the first and second linear arrays.

45. A method of operating a distributed antenna comprising:

arranging a plurality of transmit antenna elements in an array;

arranging a plurality of receive antenna elements in an array;

coupling a power amplifier with each of said transmit antenna elements mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element;

providing at least one low noise amplifier built into said distributed antenna for receiving and amplifying signals from at least one of said receive antenna elements;

simultaneously transmitting from said transmit antenna elements and receiving from said receive antenna elements; and

further including arranging said transmit antenna elements and said receive antenna elements in a single linear array in alternating order.

46. A method of operating a distributed antenna comprising:

arranging a plurality of transmit antenna elements in an array;

arranging a plurality of receive antenna elements in an array;

coupling a power amplifier with each of said transmit antenna elements mounted closely adjacent to the associated transmit antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element;

providing at least one low noise amplifier built into said distributed antenna for receiving and amplifying signals from at least one of said receive antenna elements;

simultaneously transmitting from said transmit antenna elements and receiving from said receive antenna elements; and

further including polarizing said transmit antenna elements in one polarization and polarizing the receive antenna elements orthogonally to the polarization of said transmit antenna elements.

47. An antenna system installation comprising a tower/support structure, and an antenna structure mounted on said tower/support structure, said antenna structure comprising:

a plurality of antenna elements;

a plurality of power amplifiers, each power amplifier being operatively coupled with one of said antenna elements and mounted closely adjacent to the associated antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element;

each said power amplifier comprising a relatively low power, relatively low cost per watt linear power amplifier chip;

a first RF to fiber transceiver mounted on said tower/support structure and operatively coupled with said antenna structure; and

a second RF to fiber transceiver mounted adjacent a base portion of said tower/support structure and coupled with said first RF transceiver by an optical fiber cable.

48. A method of installing an antenna system on a tower/support structure, said method comprising:

mounting a plurality of antenna elements arranged in an antenna array on said tower/support structure;

coupling a power amplifier comprising a relatively low power, relatively low cost per watt linear power amplifier chip with each of said antenna elements mounted closely adjacent to the associated antenna element, such that no appreciable power loss occurs between the power amplifier and the associated antenna element; and

mounting a first RF to fiber transceiver on said tower/support structure, and coupling said first RF to fiber transceiver with said antenna structure; and mounting a second RF to fiber transceiver adjacent a base portion of said tower/support structure, and coupling said second RF to fiber transceiver with said first RF to fiber transceiver by an optical fiber cable.

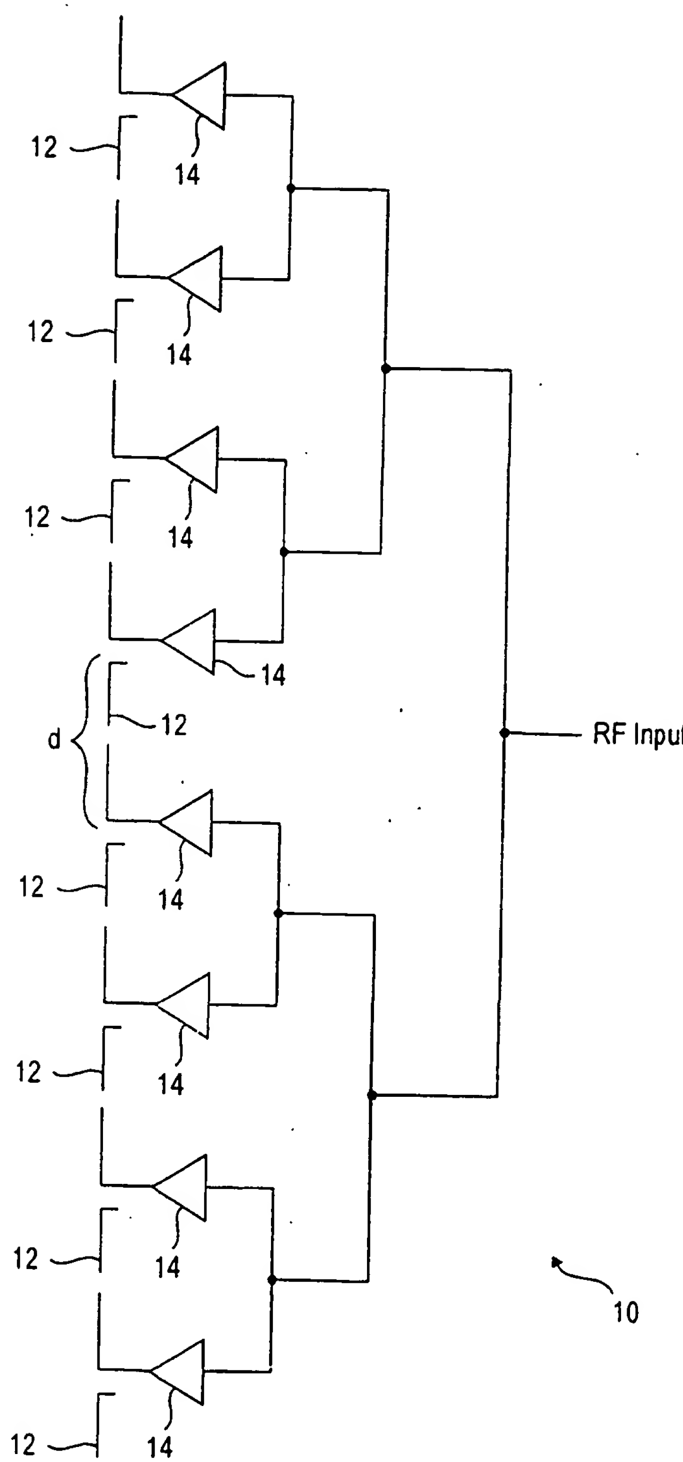

FIG. 1

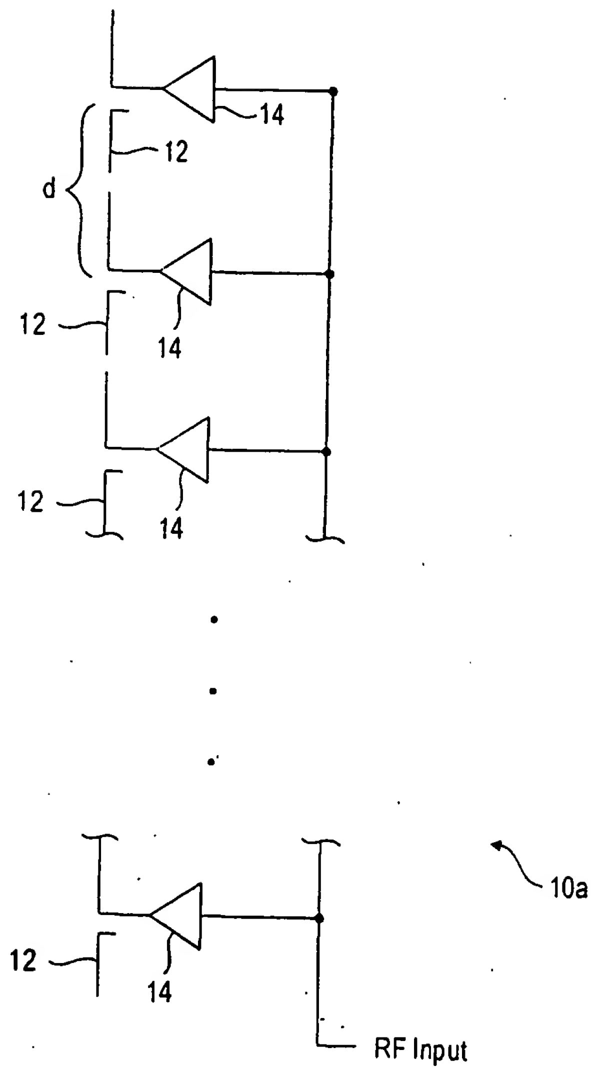

FIG. 2

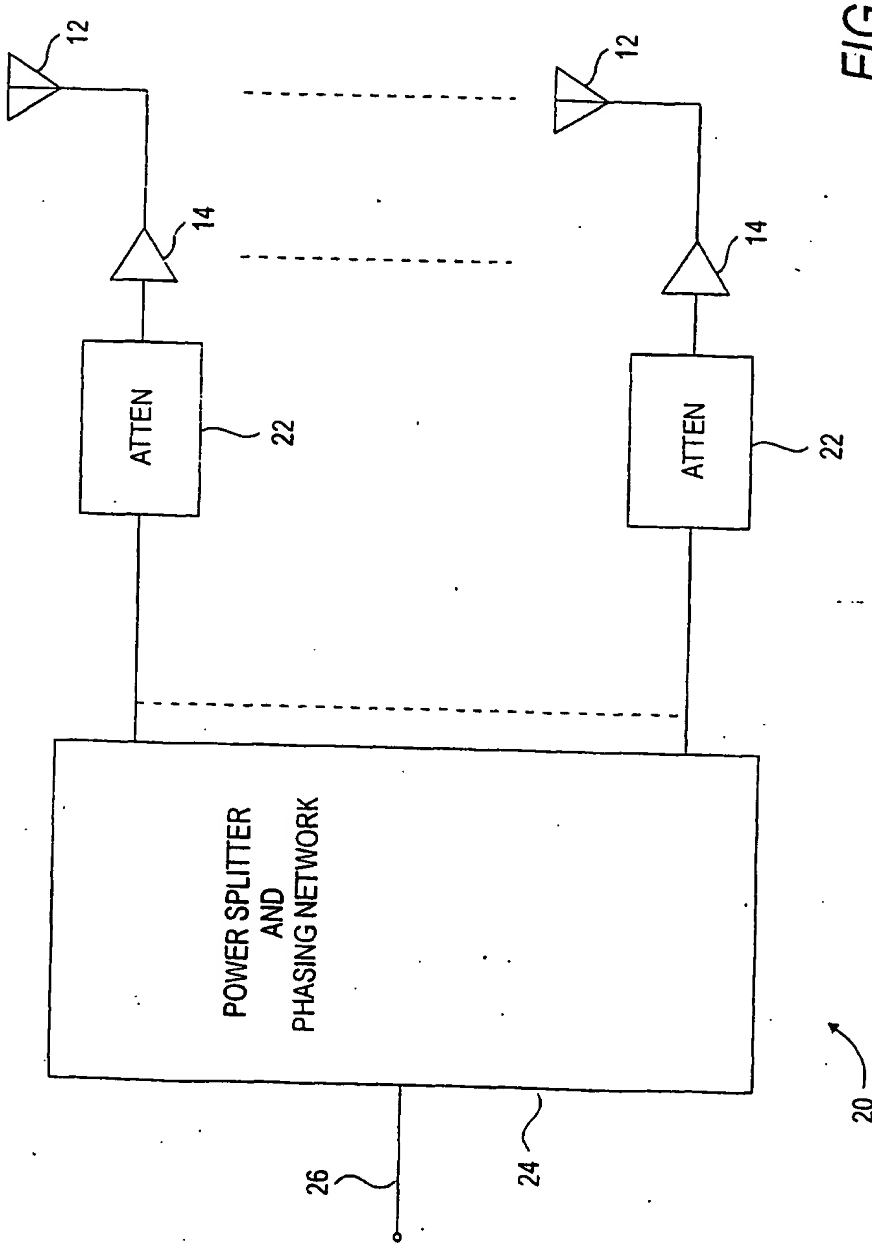
12
12
14
14
ATTEN
ATTEN
22
22
POWER SPLITTER
AND
PHASING NETWORK
24
26
20

FIG. 3

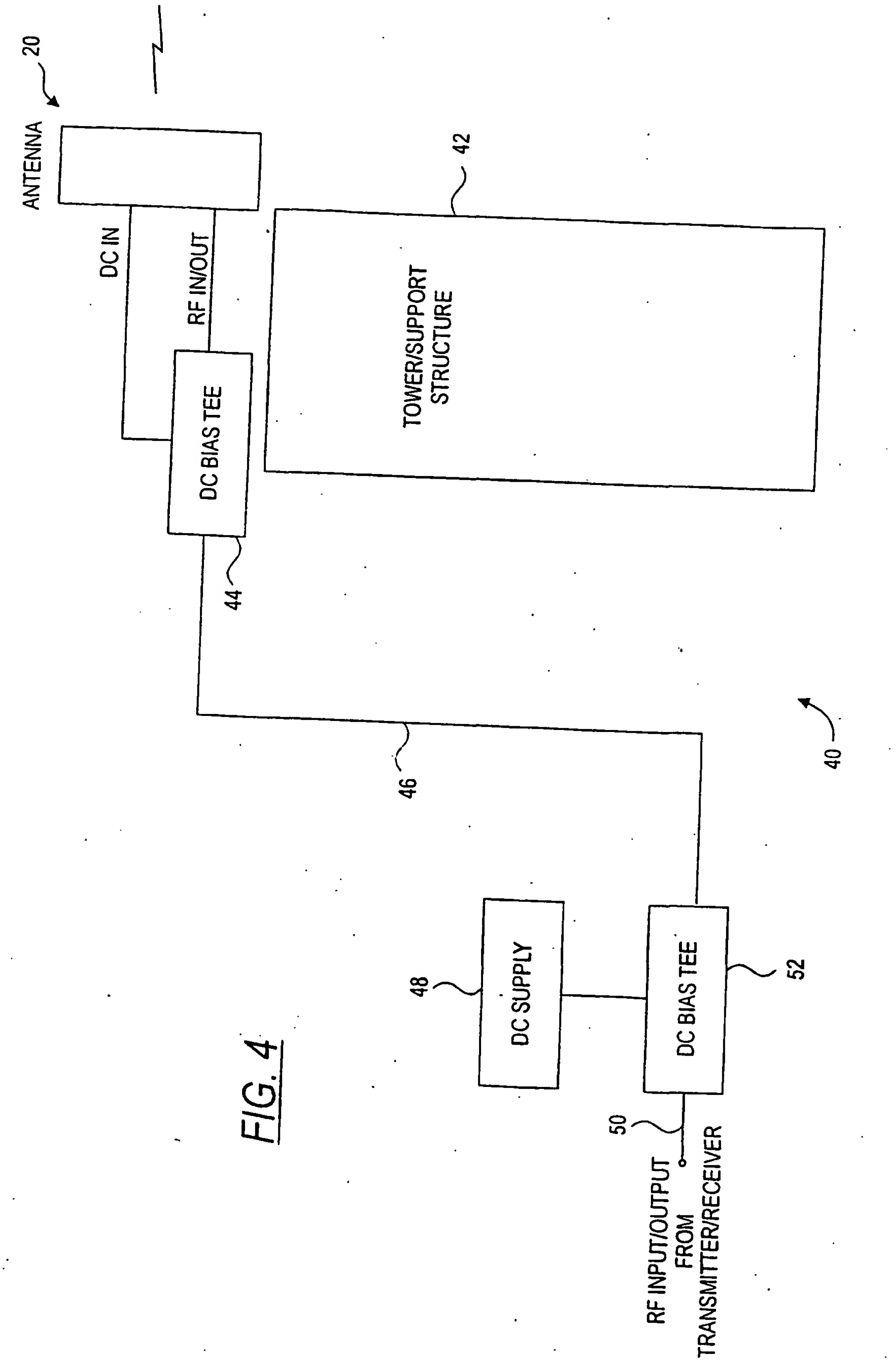
20
ANTENNA
DC IN
RF IN/OUT
42
TOWER/SUPPORT STRUCTURE
DC BIAS TEE
44
46
40
48
DC SUPPLY
DC BIAS TEE
52
50
RF INPUT/OUTPUT FROM TRANSMITTER/RECEIVER

FIG. 4

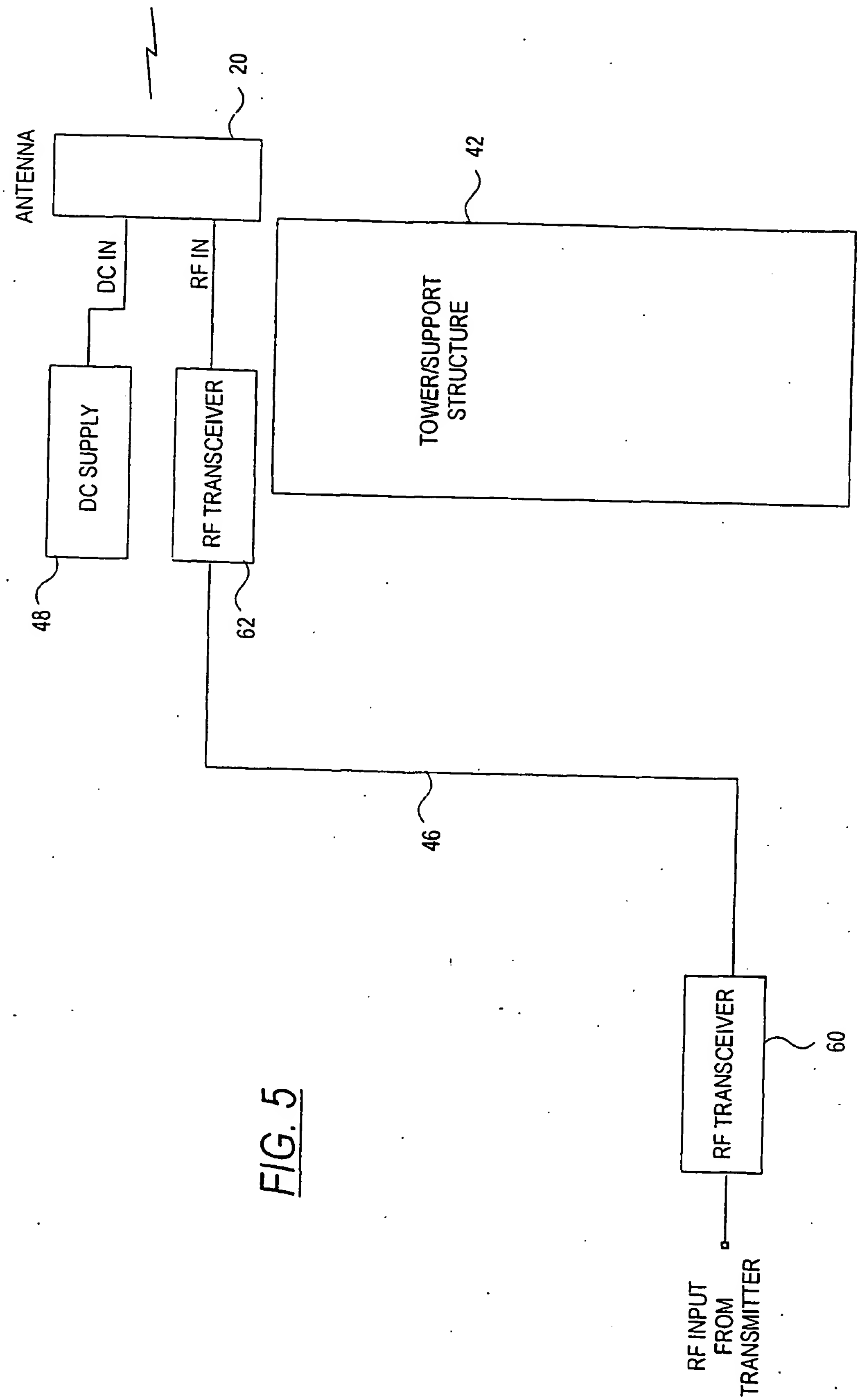
ANTENNA
20
DC IN
RF IN
42
TOWER/SUPPORT STRUCTURE
DC SUPPLY
RF TRANSCEIVER
48
62
46
RF TRANSCEIVER
60
RF INPUT FROM TRANSMITTER

FIG. 5

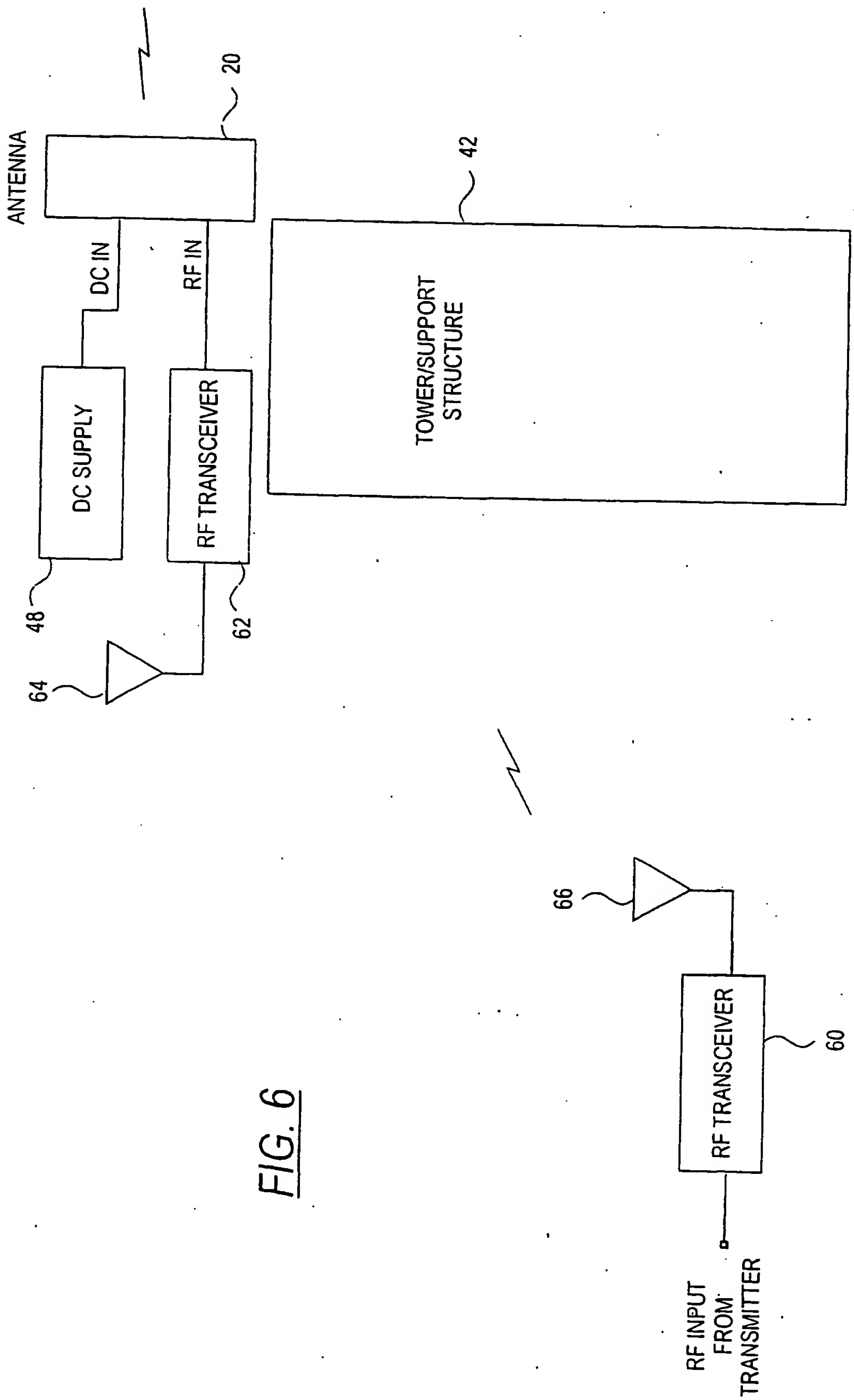
ANTENNA
20
DC IN
RF IN
42
TOWER/SUPPORT STRUCTURE
DC SUPPLY
RF TRANSCEIVER
48
62
64
66
RF TRANSCEIVER
60
RF INPUT FROM TRANSMITTER

FIG. 6

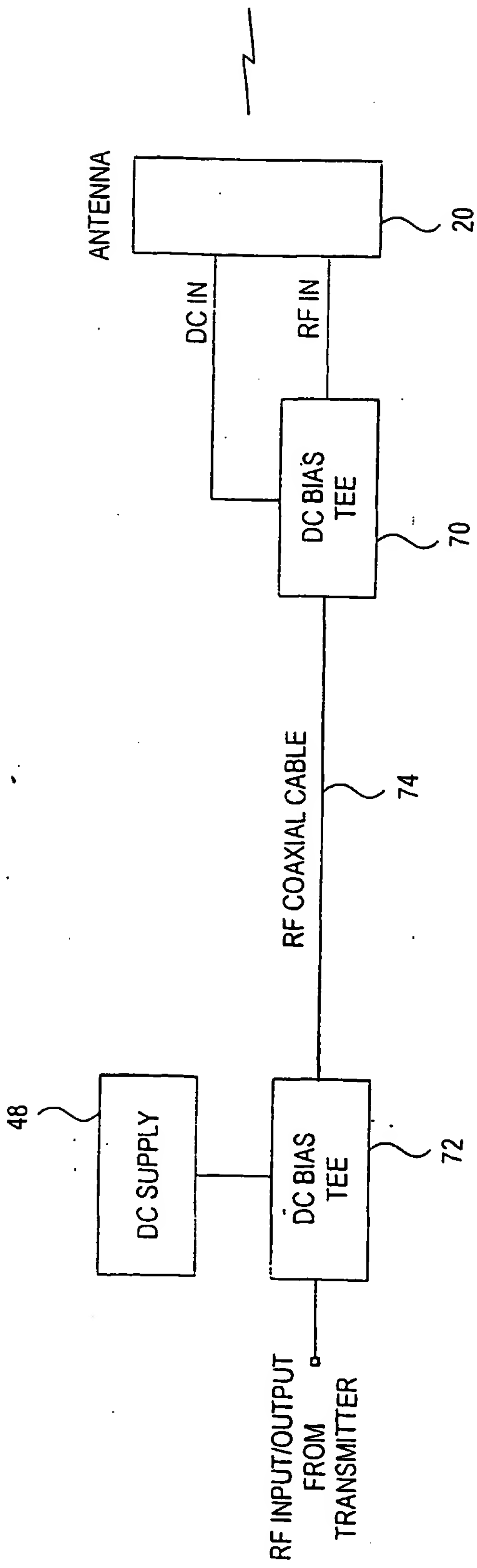
ANTENNA
20
DC IN
RF IN
DC BIAS TEE
70
RF COAXIAL CABLE
74
48
DC SUPPLY
DC BIAS TEE
72
RF INPUT/OUTPUT FROM TRANSMITTER

FIG. 7

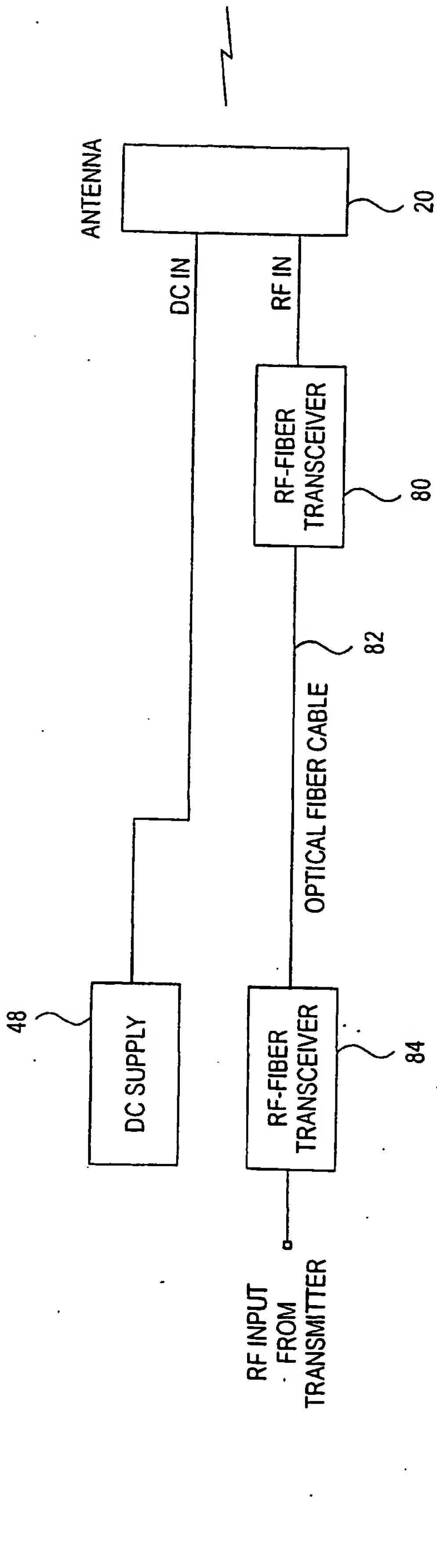
ANTENNA
20
DC IN
RF IN
RF-FIBER TRANSCEIVER
80
82
OPTICAL FIBER CABLE
48
DC SUPPLY
RF-FIBER TRANSCEIVER
84
RF INPUT FROM TRANSMITTER

FIG. 8

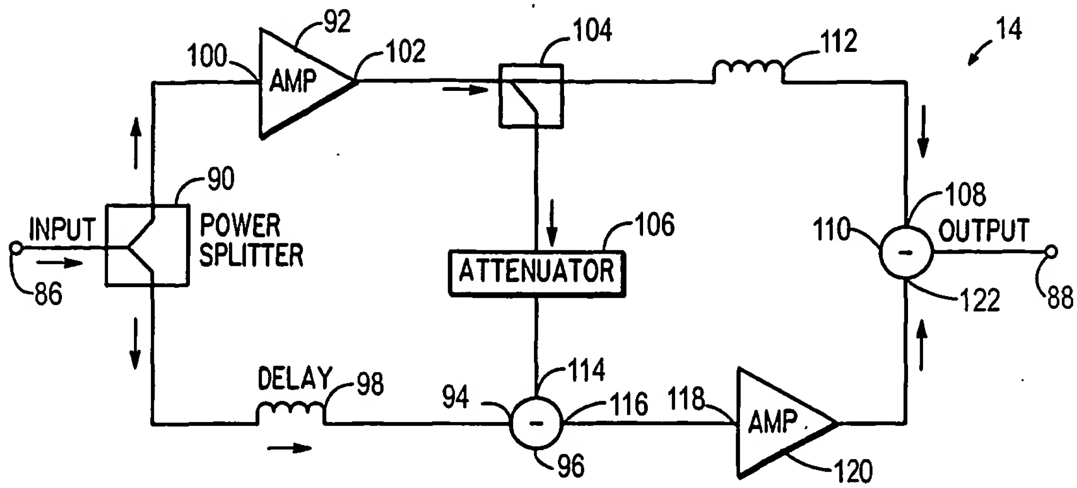
14
100
AMP
92
102
104
112
90
INPUT
POWER SPLITTER
86
106
ATTENUATOR
110
108
OUTPUT
122
88
DELAY
98
94
114
116
118
AMP
96
120

FIG. 8A

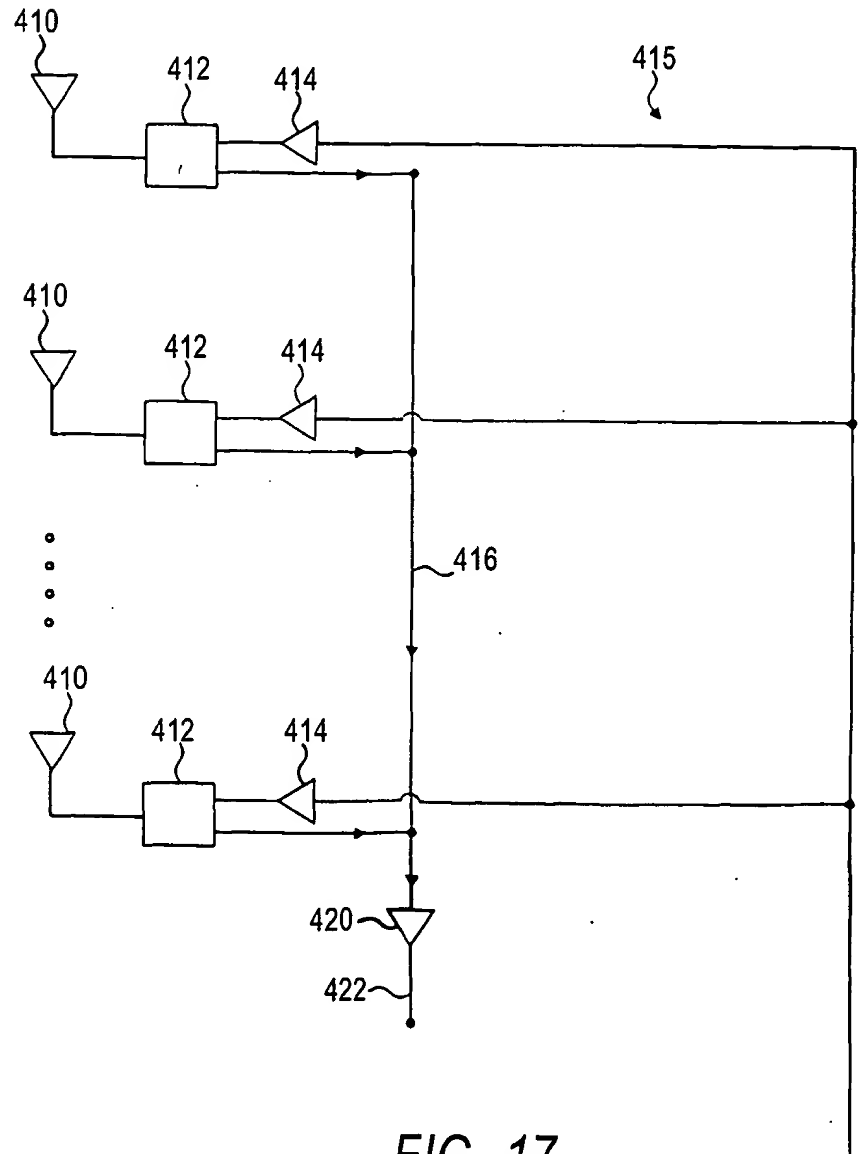
410
412
414
415
410
412
414
416
410
412
414
420
422

FIG. 17

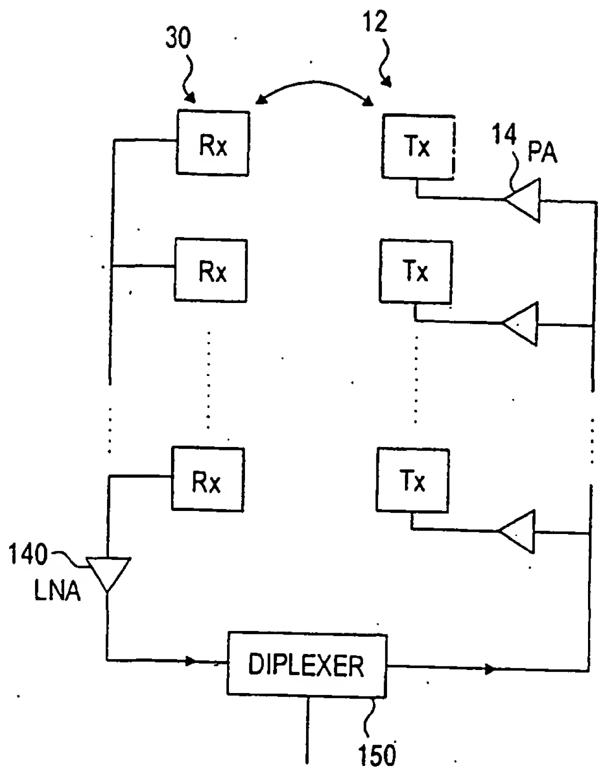
30
12
Rx
Tx
14
PA
Rx
Tx
Rx
Tx
140
LNA
DIPLEXER
150

FIG. 9

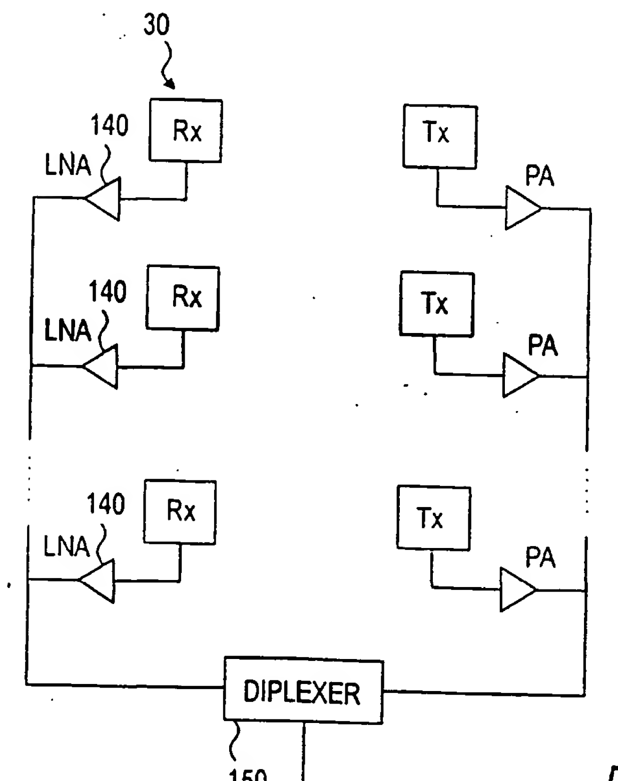
30
140
LNA
Rx
Tx
PA
140
LNA
Rx
Tx
PA
140
LNA
Rx
Tx
PA
DIPLEXER
150

FIG. 10

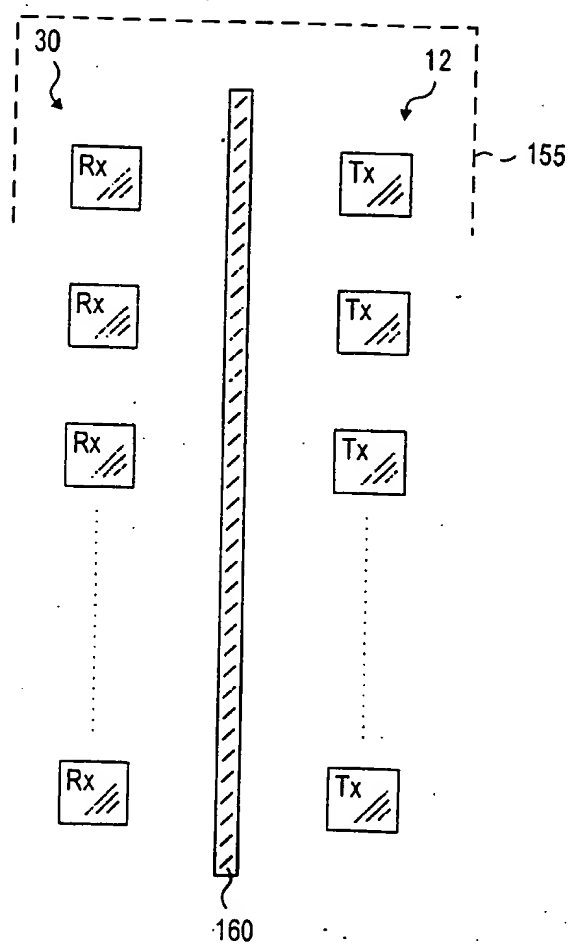

FIG. 11

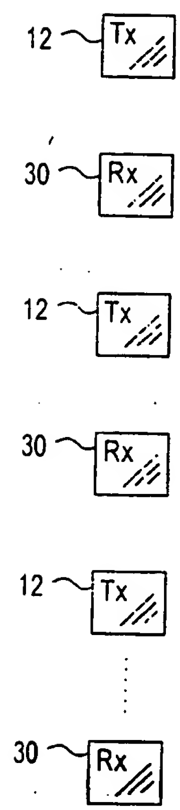

FIG. 12

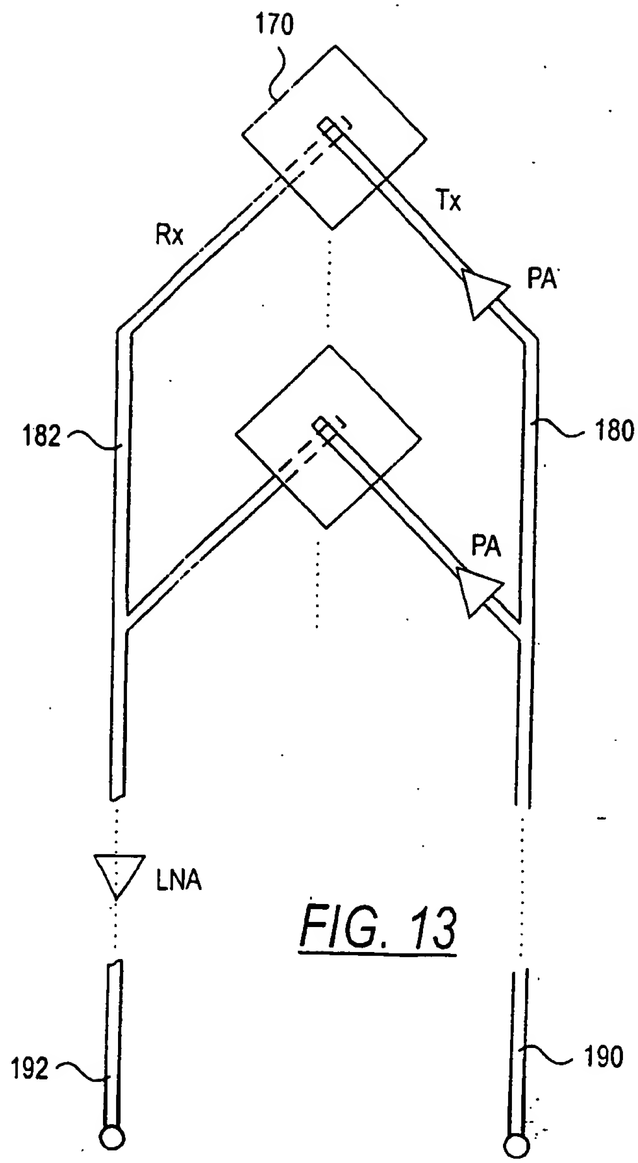
170
Rx
Tx
PA
182
180
PA
LNA
192
190

FIG. 13

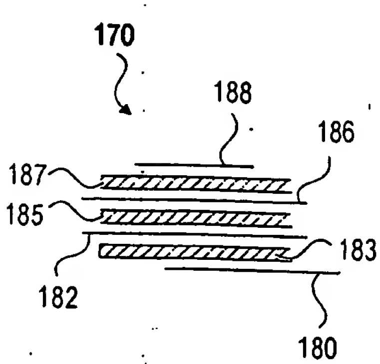
170
188
186
187
185
183
182
180

FIG. 14

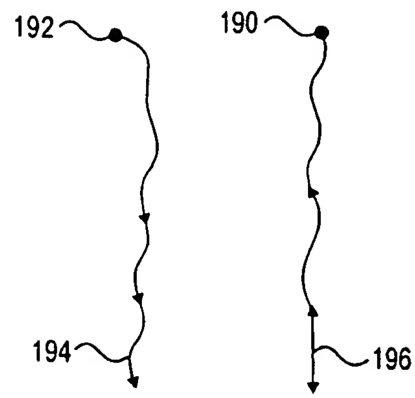

FIG. 15

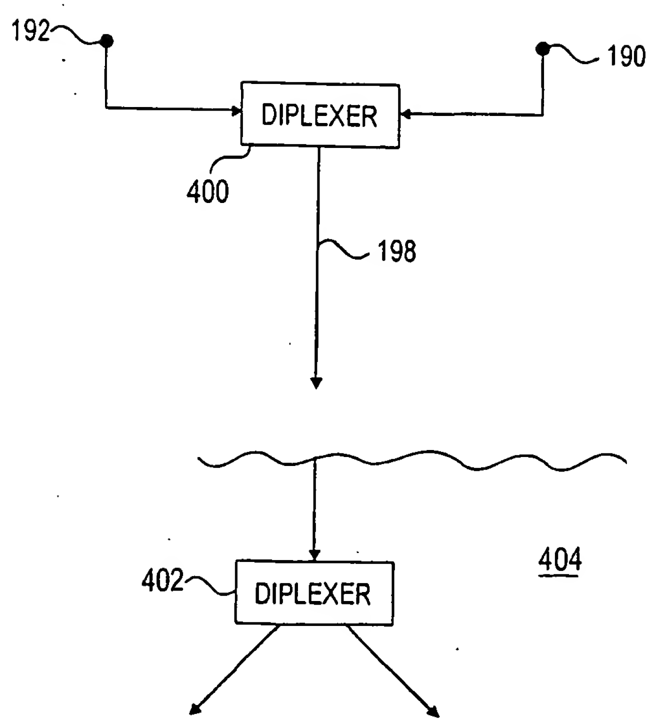

FIG. 16

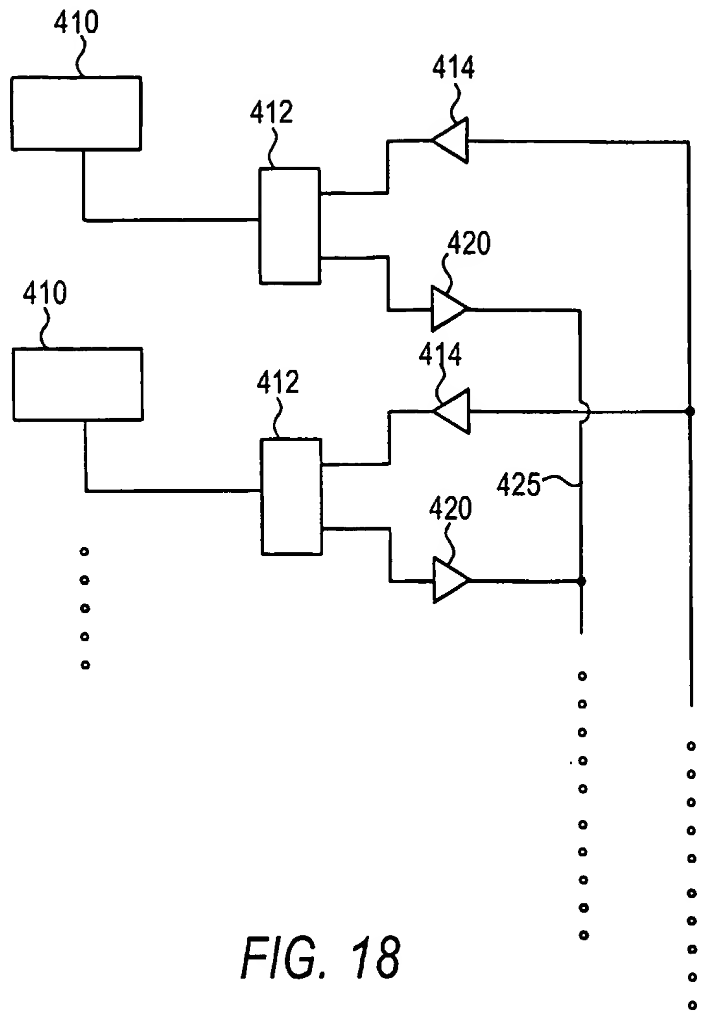

FIG. 18

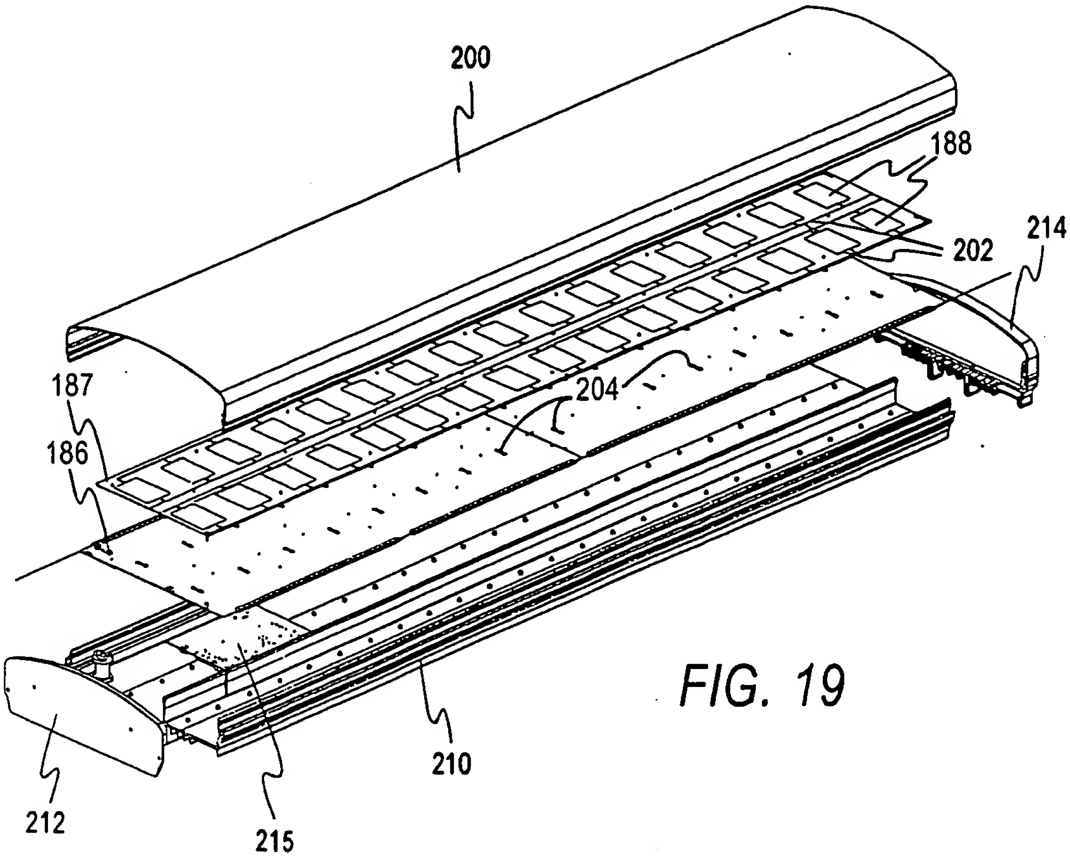

FIG. 19

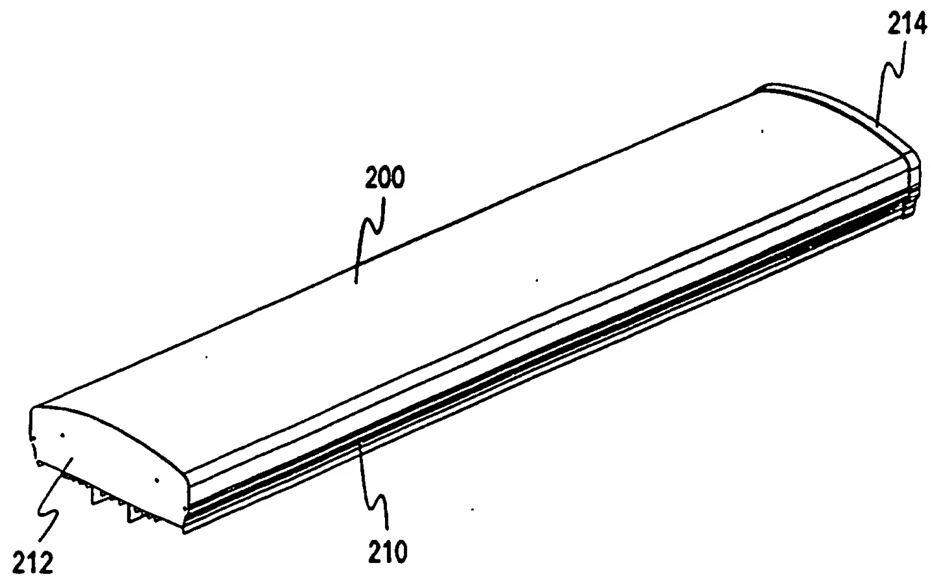

FIG. 20

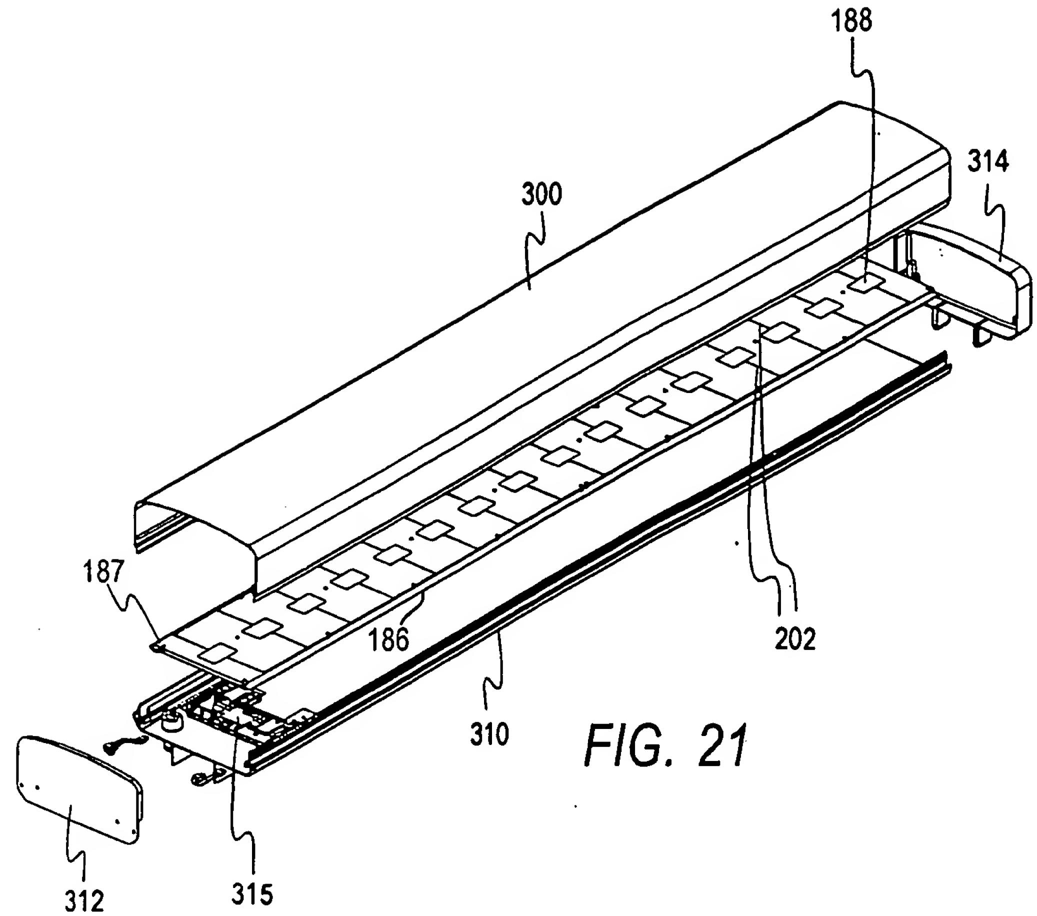

FIG. 21

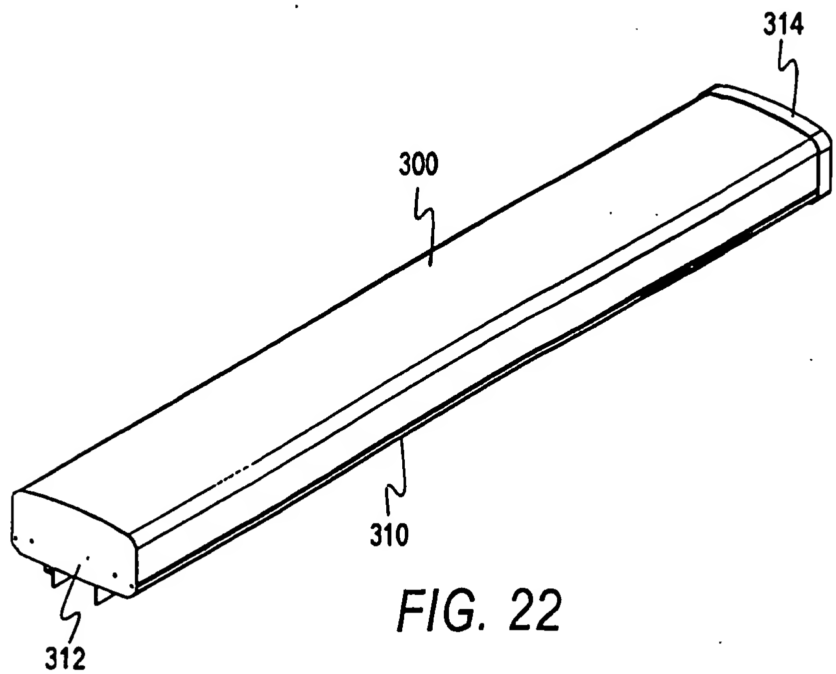

FIG. 22